Dilepton results from HADES using Au+Au data at 1.23 AGeV

MENU 2016 – July 25-30, Kyoto, Japan

Celso Franco *(LIP-Lisboa)*
on behalf of the HADES collaboration

LIP

HADES

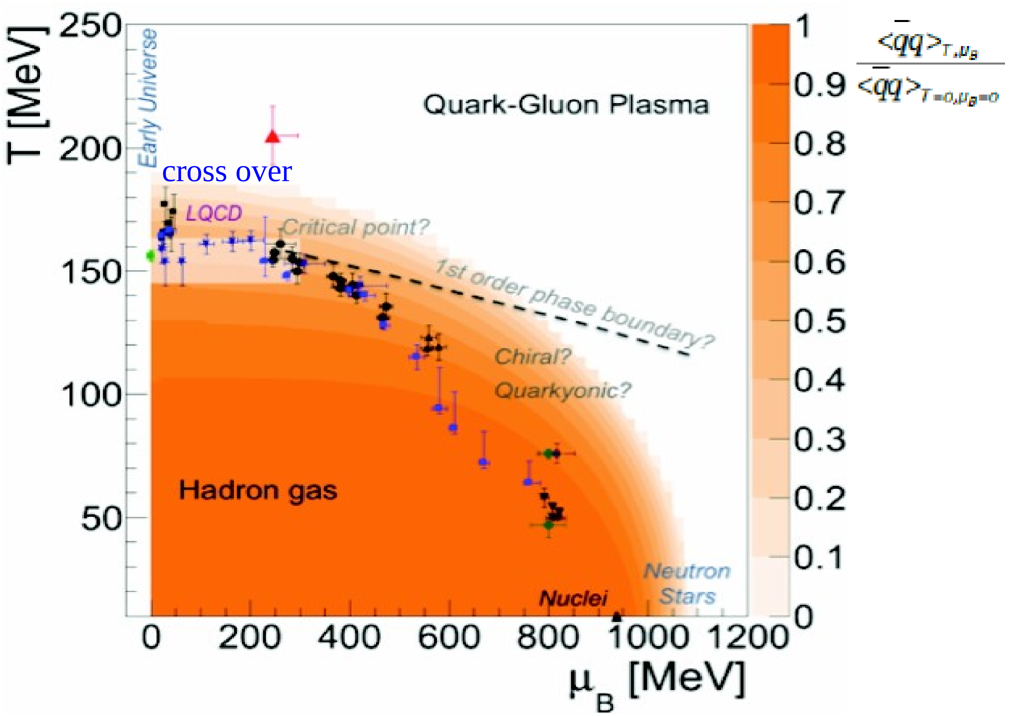
FCT
Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

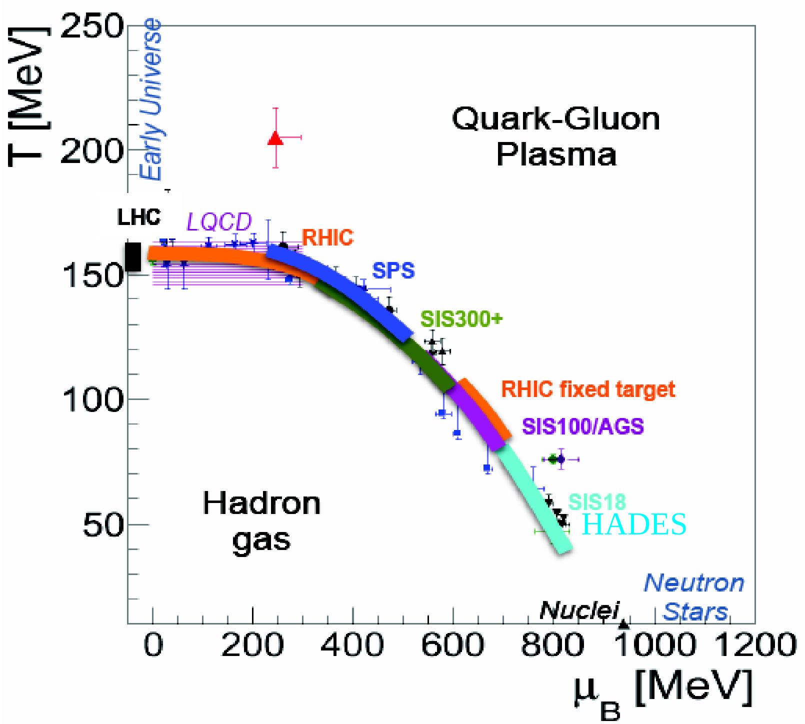
FUNDAÇÃO ORIENTE

Phase diagram of matter: From the Big-Bang to the Neutron stars

- The main goal of Heavy-Ion Physics is to establish the nature of phase transitions in matter. Namely, under which temperature and pressure does matter deconfine and/or restore its chiral symmetry *(mass degeneration)*? <u>The answers to these questions will surely improve our knowledge about the mass generation in hadrons</u>

T. Galatyuk et al. (HADES Collab) Nucl. Phys. A931 (2014) 41-51



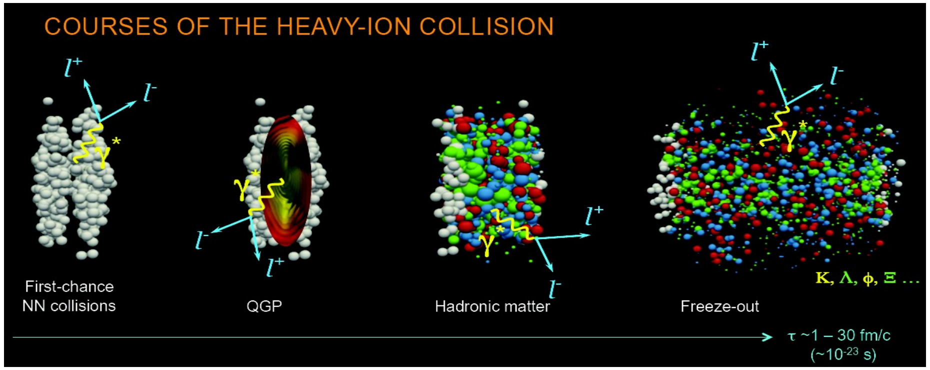


LQCD: Z. Fodor et al., hep-lat/0402006
Condensate: B.J. Schaefer and J. Wambach, private communication
HADES data: M. Lorenz et al., Nucl. Phys. A(2014) QM14
A.Andronic et al., Nucl. Phys. A 837 (2010) 65
J. Cleymans et al., Phys. Rev. C 60 (1999_) 054908

Electromagnetic *(EM)* probes in Heavy-Ion collisions

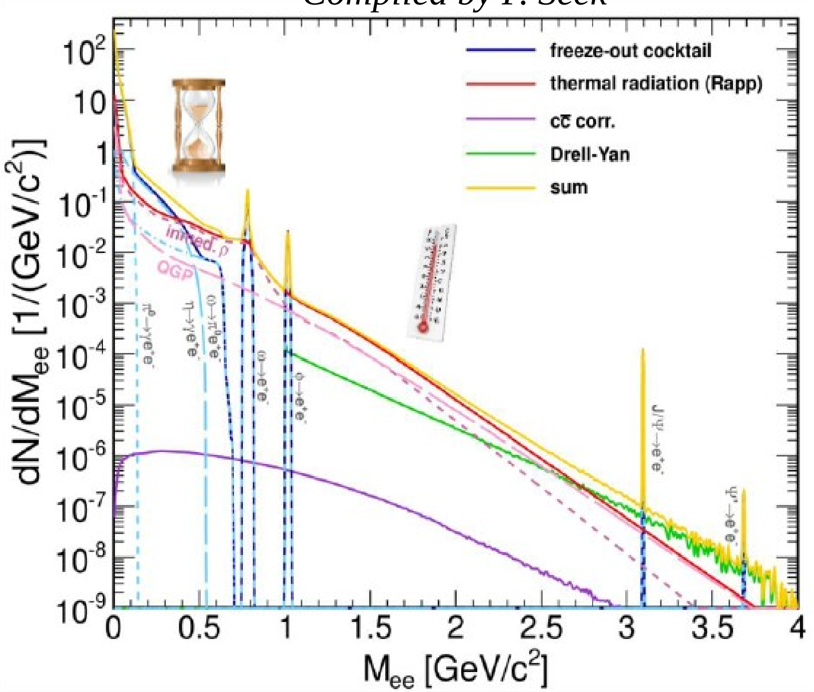
- **Why Dileptons?**
  - They are emitted during the whole history of a Heavy-Ion collision
  - They leave the reaction volume *(fireball)* undisturbed: <u>no strong interaction within the fireball</u>

MADAI.ua



- The dilepton mass spectrum represents the space-time integral of EM radiation:

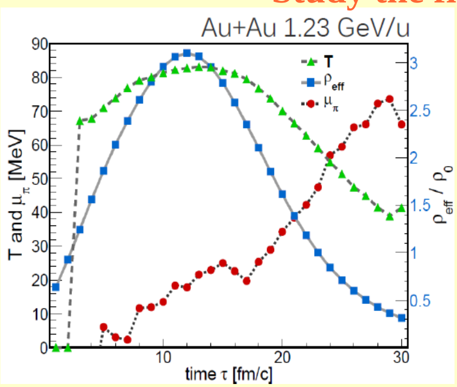
Compiled by F. Seck

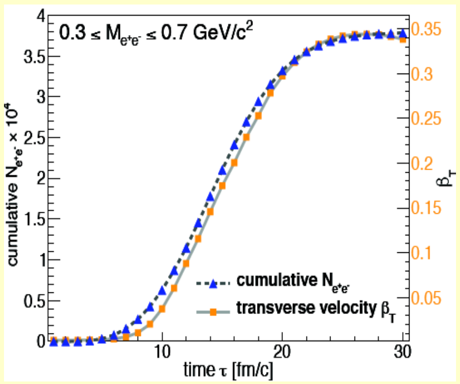


Mass dependence allows the separation of collision stages:

- $0.3 < M_{ee} < 0.7$ GeV/c^2: <u>strong correlation between thermal radiation and collective flow</u> *(T. Galatyuk et al., Eur. Phys. J. A, 52 5 (2016) 131)*

Study the fireball lifetime!

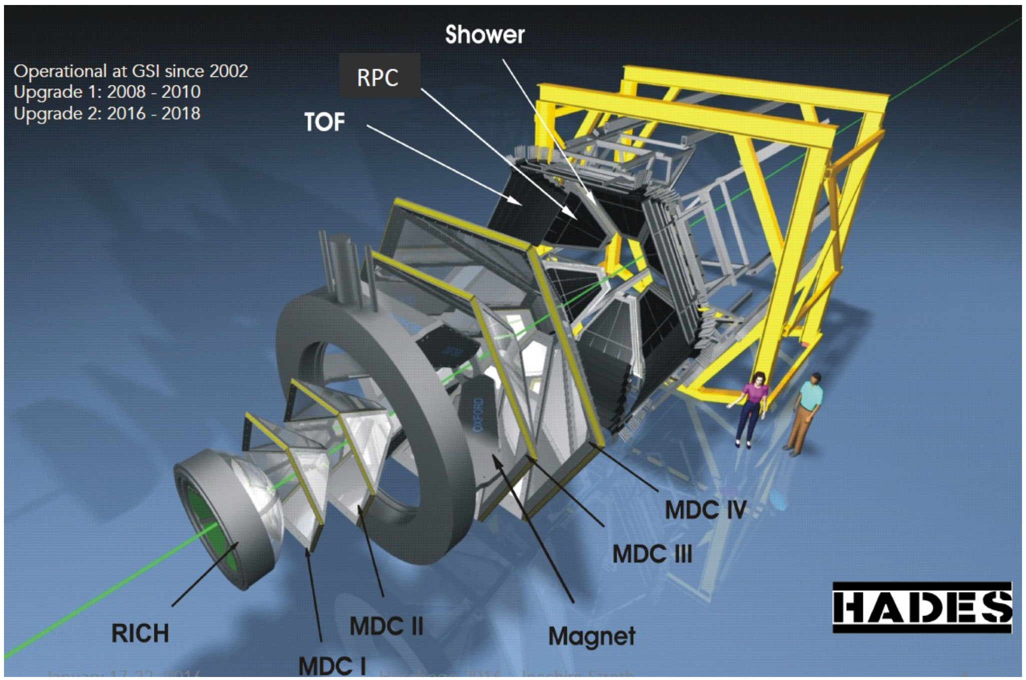


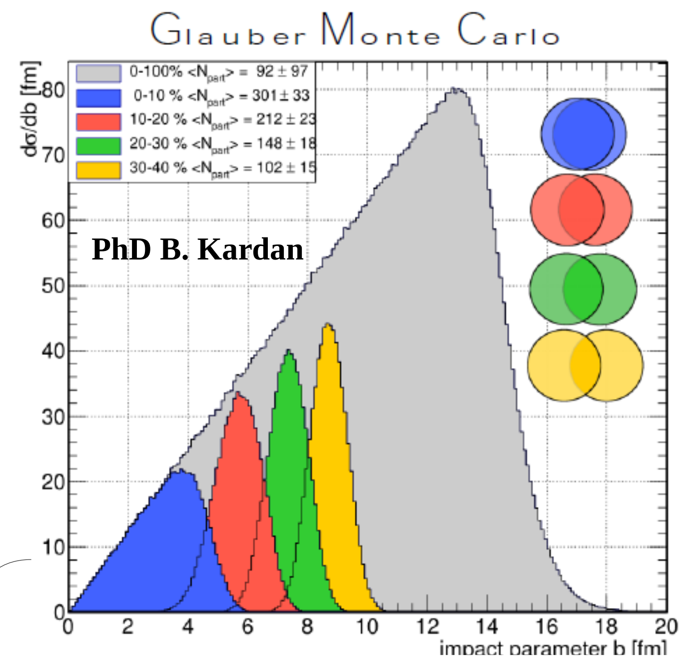


- $1.5 < M_{ee} < 2.5$ GeV/c^2: accesses earlier stages and provides a <u>stable "thermometer"</u> *(R. Rapp and H. Van Hees, Phys. Lett. B753 (2016) 586-590)*

The HADES experiment at GSI: **Fixed target setup using <u>proton</u> *(1-4 GeV)*, <u>pion</u> *(0.4-2 GeV)* and <u>nuclei</u> *(1-2 AGeV)* beams from SIS18**

- <u>Spectrometer optimized for the search of rare probes</u>
  - Dielectrons *(supressed by α^2)* → BR ~ 10^{-5}
  - Sub-threshold vector mesons





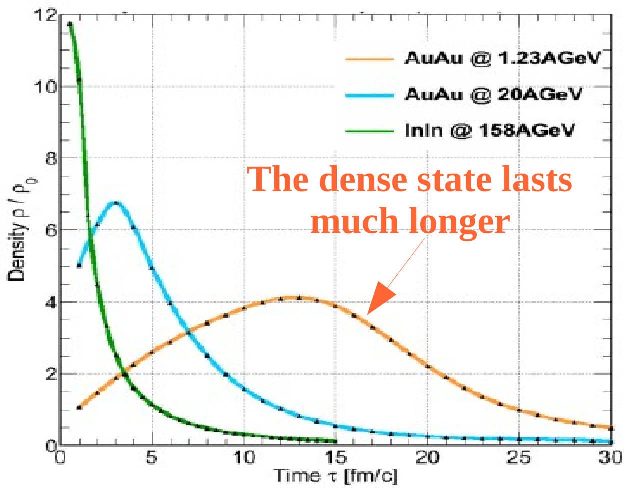
Data recorded: 4.3 x 10^9 of 40% most central Au+Au events

- **Fast detector** → <u>interaction rate of 8 kHz</u>
- **Large acceptance:** 18º < θ < 85º *(polar angle)* and full azimuthal coverage
- **Particle identification of p/π/K:** dE/dx in MDC *(tracking)* and TOF/RPC *(time-of-flight detectors)*
- **Particle identification of electrons**: RICH *(Ring Imaging Cherenkov)* and TOF or RPC+Shower
- **Mass resolution** ~ <u>2% of M(ρ, ω)</u>

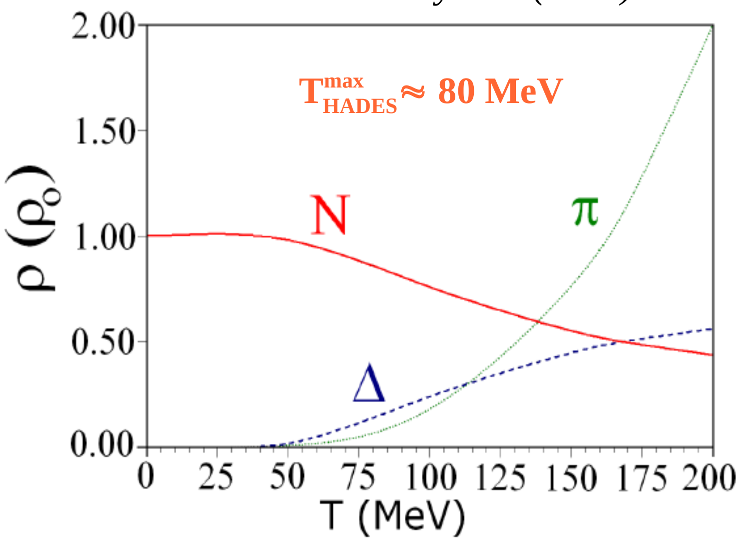
The relevance of the Au+Au program of HADES: Collisions at $\sqrt{S_{NN}} = 2.42\,\text{GeV}$

- Great conditions to study the properties of hadrons within a dense baryon-rich medium:

T. Galatyuk et al., Eur. Phys. J. A, 52 5 (2016) 131

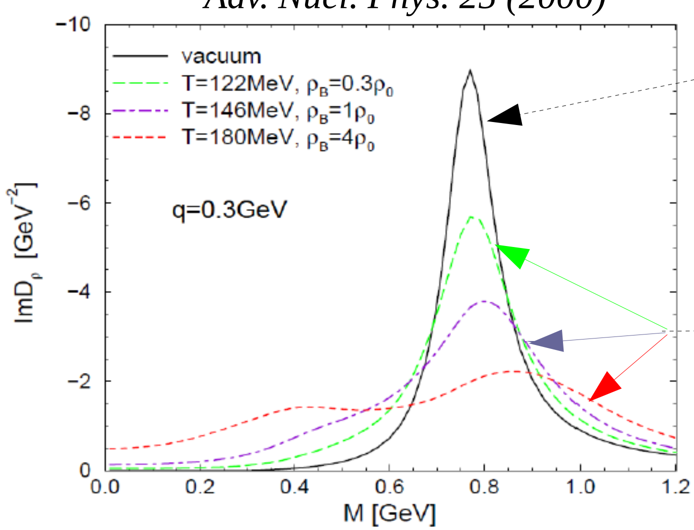


Adv. Nucl. Phys. 25 (2000)



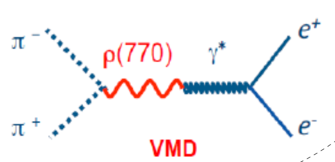
- A strong modification of the ρ *(τ ≈ 1.5 fm/c)* spectral function is expected at high baryonic density:

Adv. Nucl. Phys. 25 (2000)

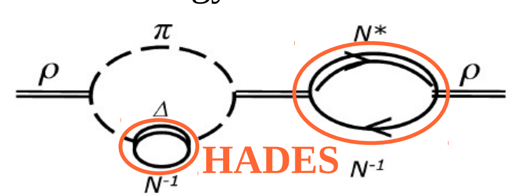


Vacuum

ρ and γ* have $J^P = 1^-$



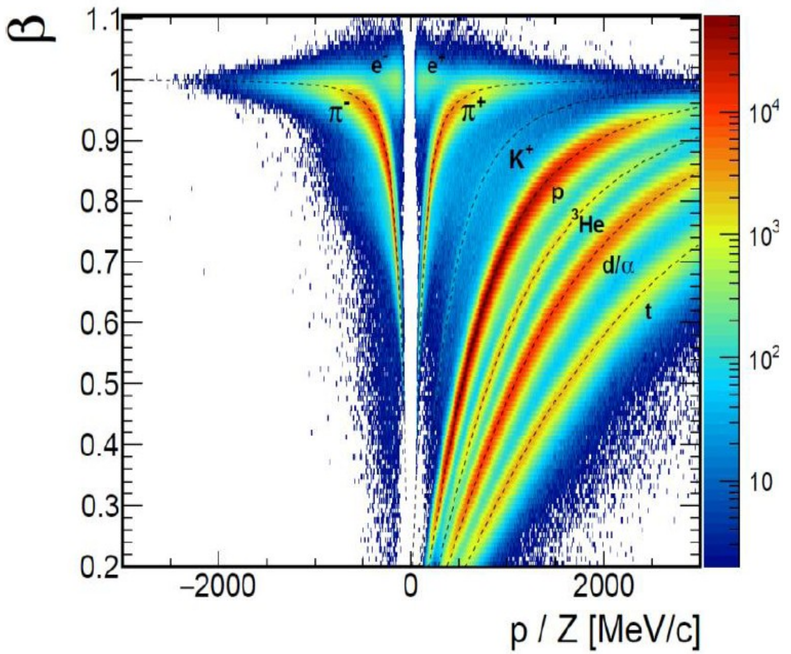
Additional contributions of the ρ self-energy in the medium



$$D_\rho(M, q; \mu_B, T) = [M^2 - m_\rho^2 - \Sigma_{\rho\pi\pi} - \Sigma_{\rho B} - \Sigma_{\rho M}]^{-1}$$

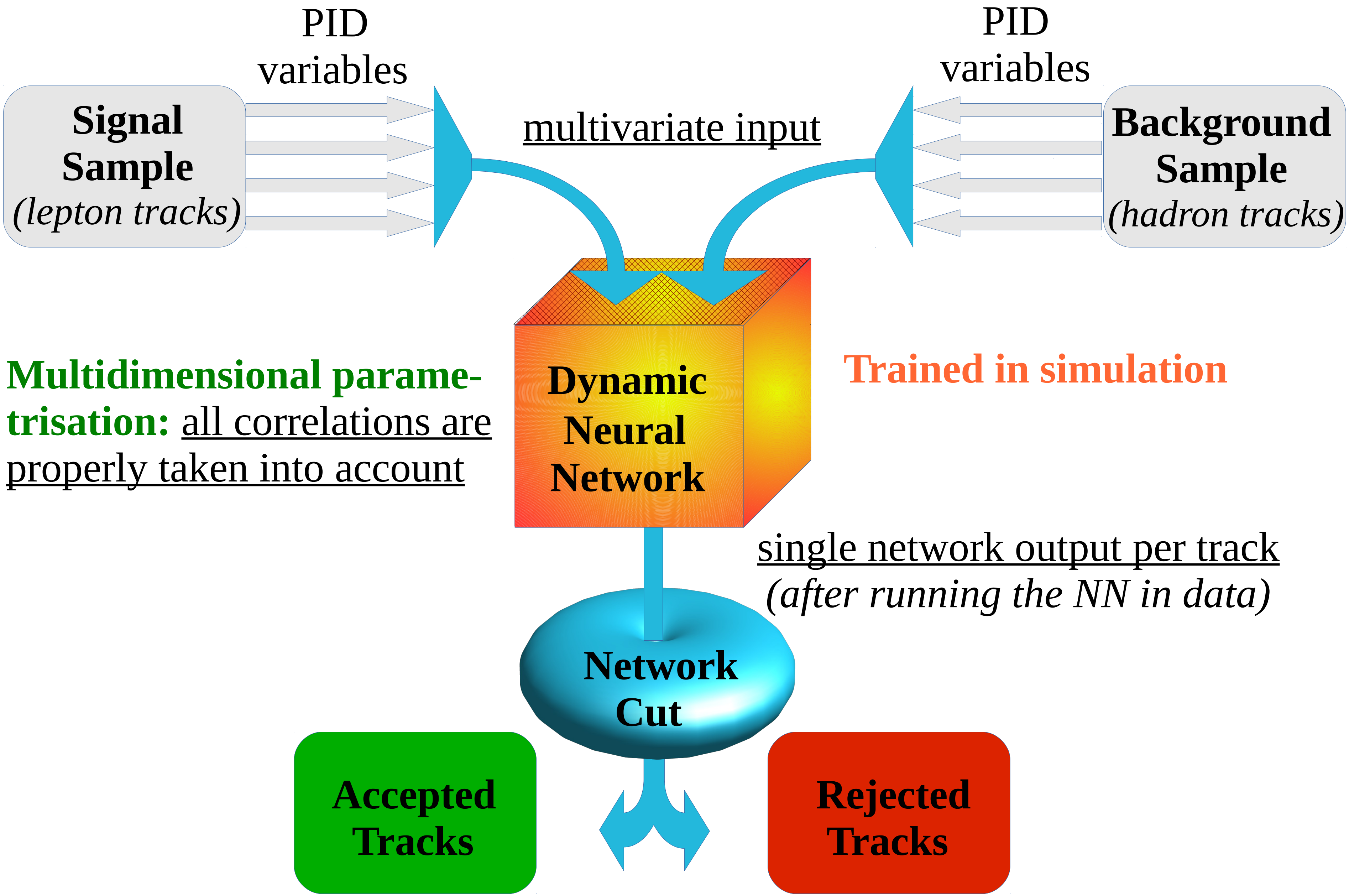
Identification of Electrons and Positrons

- **Relevant variables for the PID of leptons:**
  - Particle velocity β
  - Particle momentum p
  - Energy Loss
  - Electromagnetic Shower
  - Track quality
  - Cherenkov radiation *(emitted by particles traversing the RICH detector)*



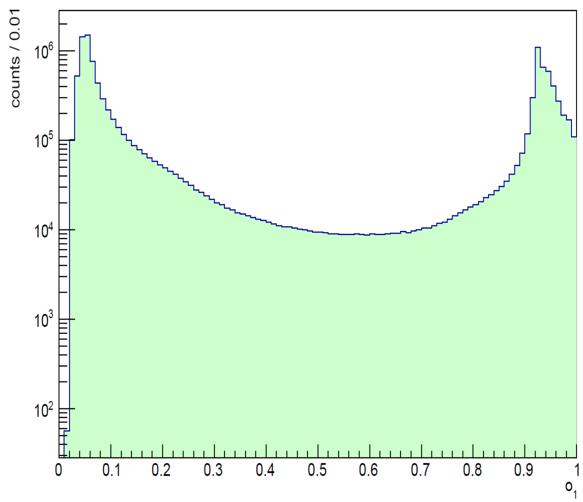
- All variables are combined in a multivariate analysis by a **Neural Network** *(NN)*
- The use of a NN improves the lepton efficiency, <u>specially at high-momentum</u>, due to the consideration of multidimensional correlations

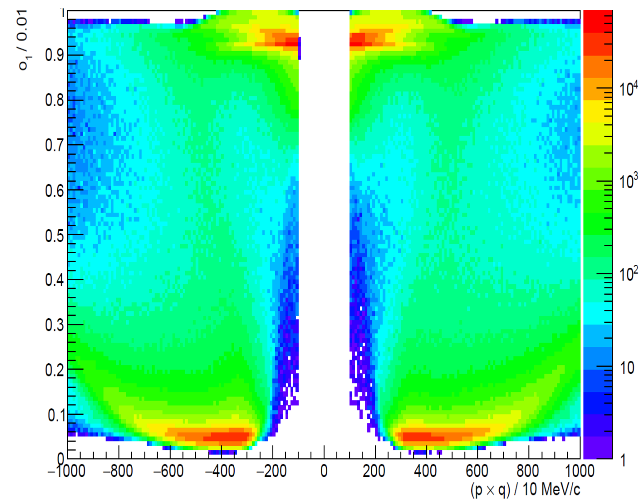
Flowchart of the method used for the PID of leptons



Efficiency and Purity of the lepton selection

- Values of o_1 (*NN output*) close to 1 indicate tracks which are kinematically similar to the simulated leptons:



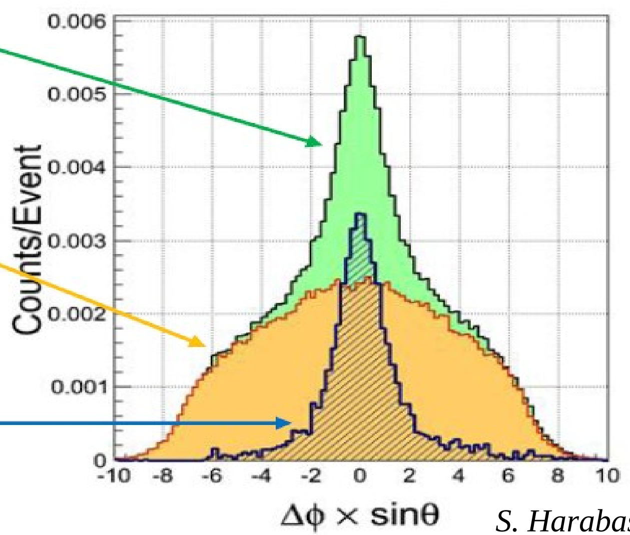


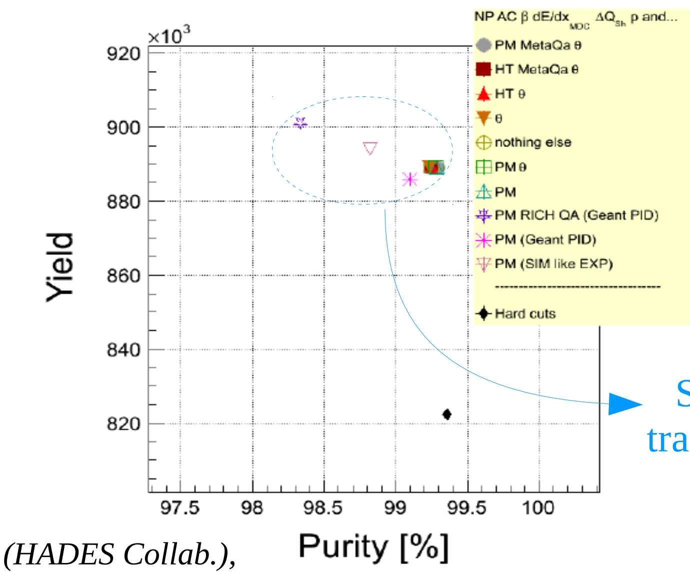
Purity estimation *(from data)*

Normal distribution

Random matches between RICH-rings and MDC tracks *(background model)*

signal





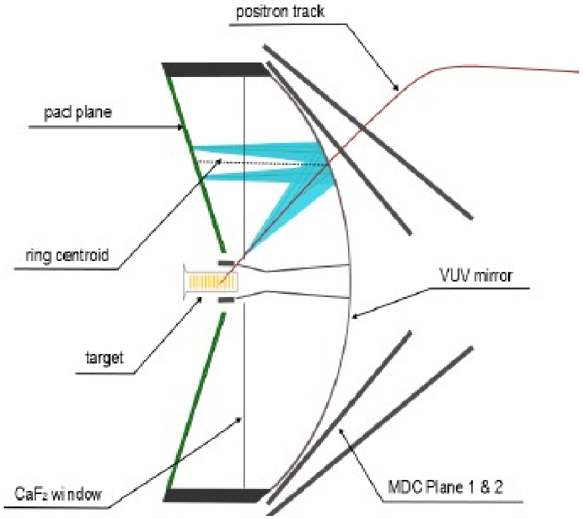
Stability of the training procedure

S. Harabasz et al. (HADES Collab.), J. Phys. Conf. Ser. 503 (2014) 012014

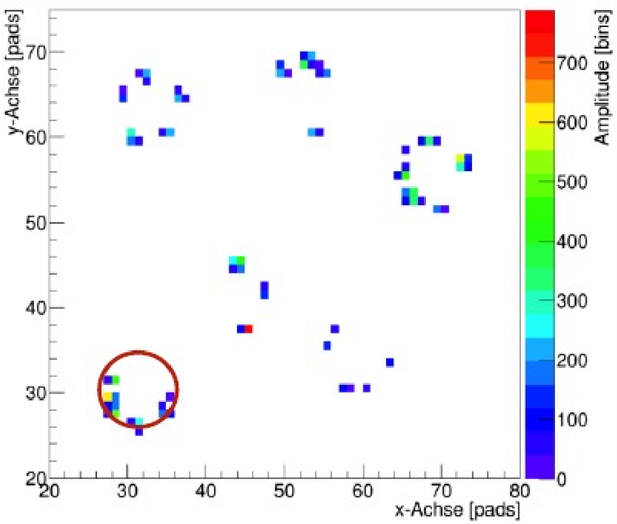
Two approaches to detect the Cherenkov radiation

1) Standard ring finder in the RICH detector via Hough transformation and pattern matrix *(S. Harabasz and C. Franco)*. <u>The angular matching between the ring centroid and the reconstructed track is used for the PID</u>

Side view of the RICH detector



Photon detector response

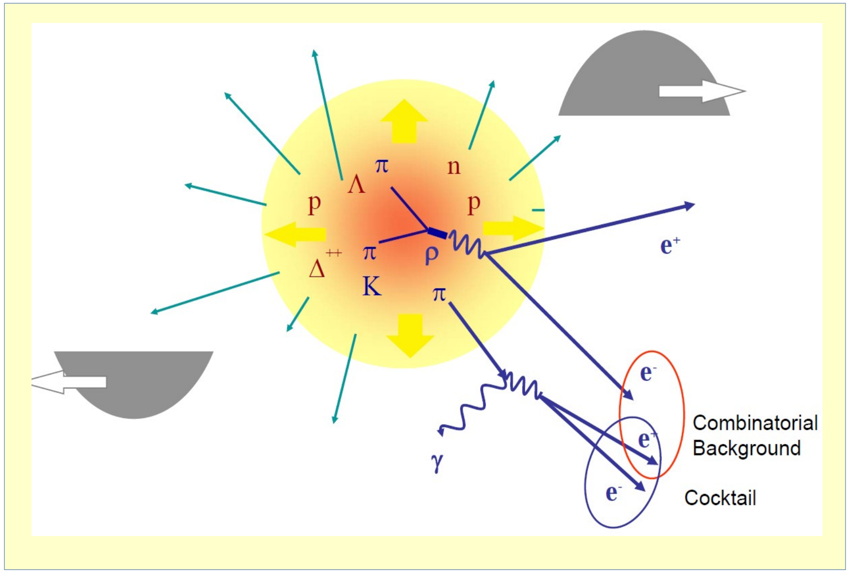


2) Backtracking algorithm *(P. Sellheim et al. (HADES Collab.), J. Phys. Conf. Ser. 599 (2015))*

- A lepton candidate is selected using the velocity and energy loss of the reconstructed track and, thereafter, the expected ring center is determined from the track's angular information
- **Advantages of the method:** avoids the multiple scattering of leptons in the mirror, allows the overlaping of rings and <u>removes close pairs from γ-conversion in the detectors</u>

Dilepton reconstruction

- **Definitions:**
  - CB *(combinatorial background)* is estimated from like-sign pairs:
    - $\mathrm{CB} = 2\sqrt{N_{e+e+} \times N_{e-e-}}$
  - The <u>dilepton signal</u>, containing thermal dileptons and the hadronic cocktail, is given by:
    - $\mathrm{Signal} = N_{e+e-} - \mathrm{CB}$

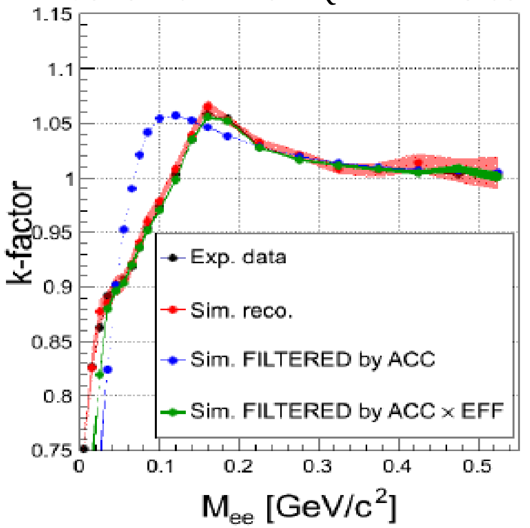


- CB is corrected for possible charge asymmetries in the spectrometer. **The correction is given by:**

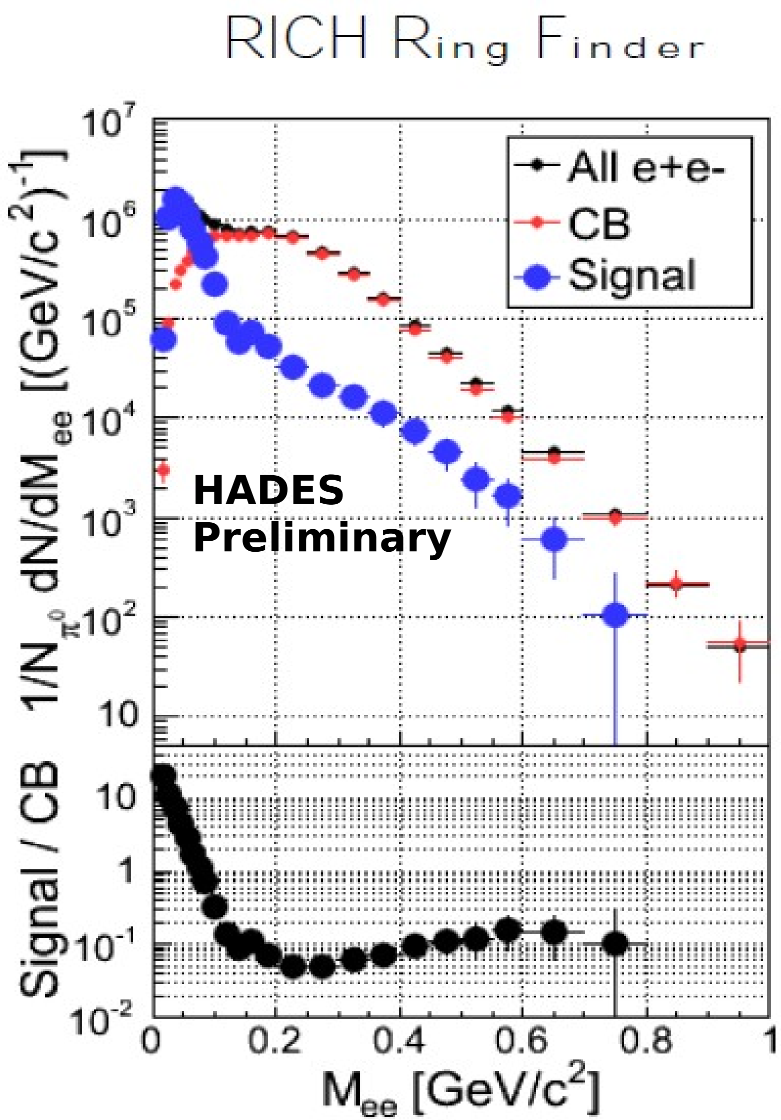
$$\boxed{k = \frac{N_{e+e-}}{\sqrt{N_{e+e+}N_{e-e-}}}} \longrightarrow \text{estimated from mixed events}$$

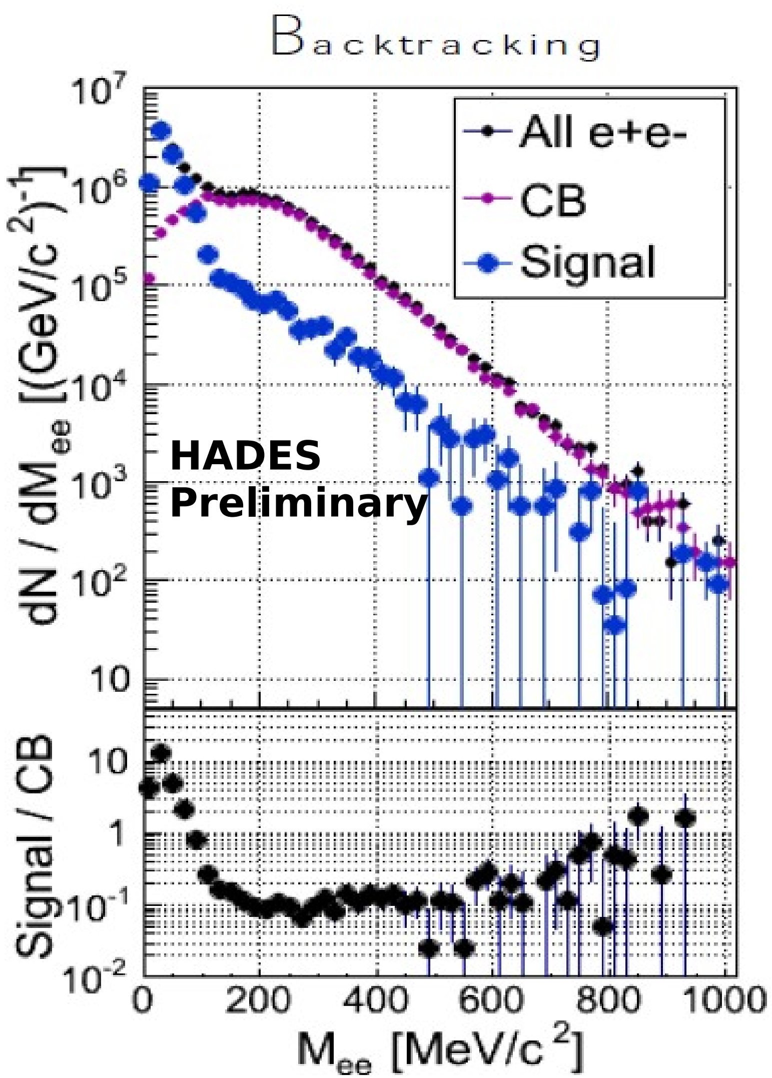
- The $\gamma \rightarrow$ e+e- *(<u>photon conversion in the spectrometer</u>)* contamination in the unlike-sign sample is removed by an opening-angle cut: **θ(e+, e-) > 9 deg**

S. Harabasz et al. (HADES Collab.), GSI-SR2014-MU-NQM-HADES-08



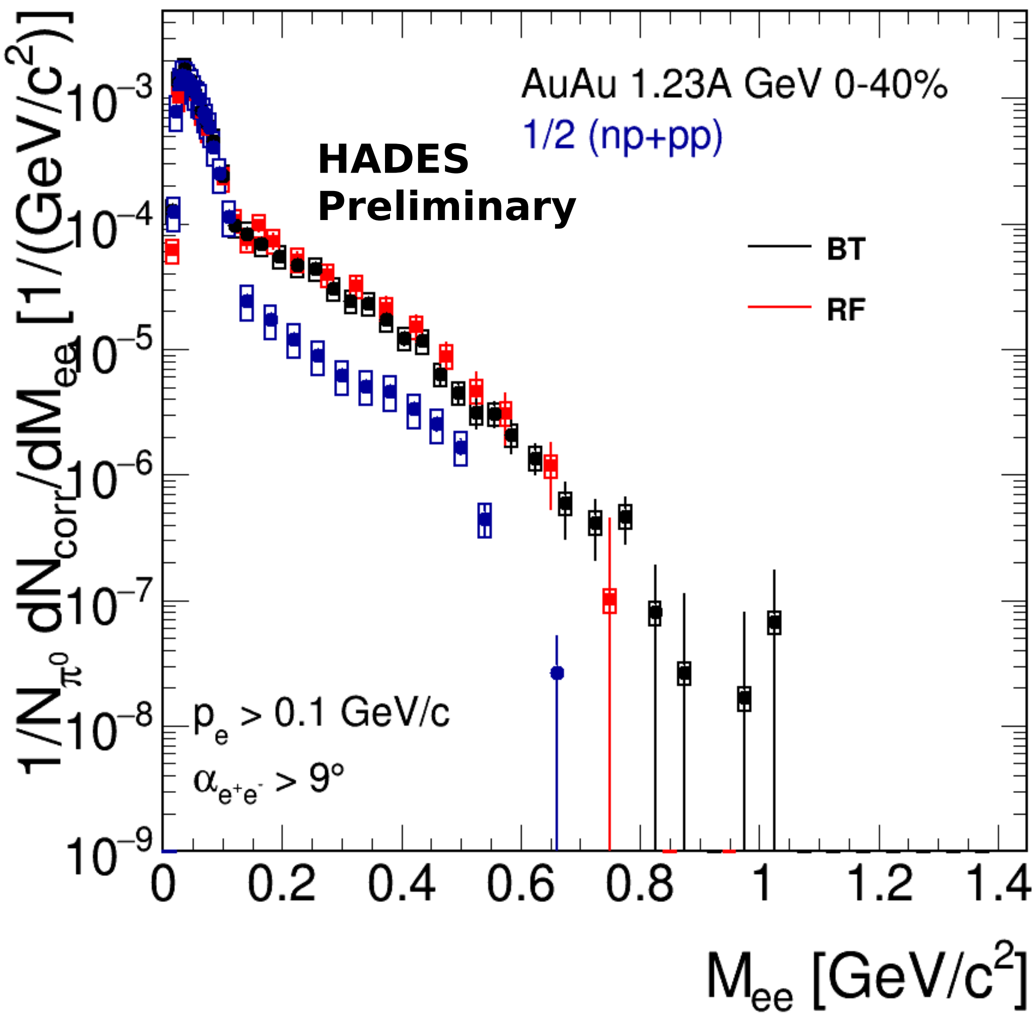
Raw invariant mass spectra





Mass spectra corrected with the efficiency of the lepton selection

(using simulated leptons embedded in real data)

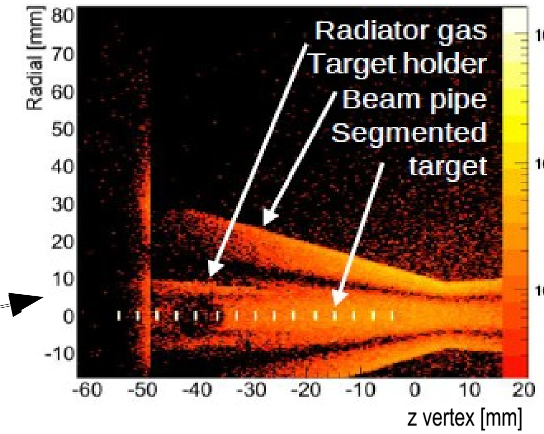


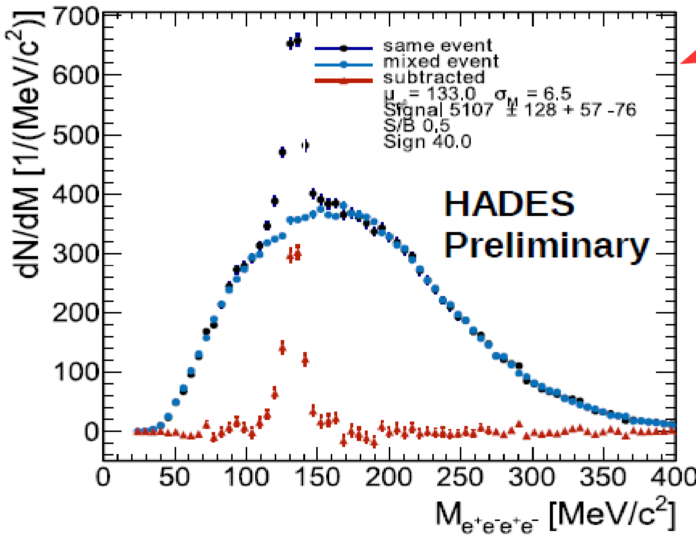
- Good agreement between the two **AuAu** analyses
- The agreement with the **1/2(np+pp)** spectrum in the **π^0-Dalitz** region reflects the consistency of the tracks reconstruction in the "dirty" AuAu environment *(up to 300 tracks/event)*
- A strong enhancement of medium radiation is observed above 150 MeV/c^2

What could be the source of this dilepton excess?

The freeze-out cocktail

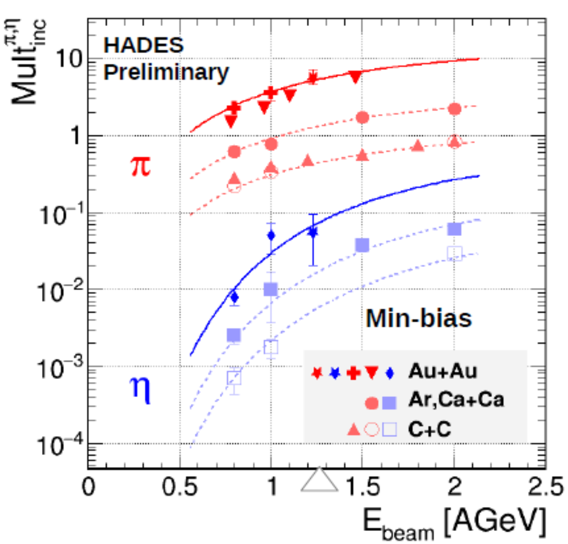
- **Constraining the dilepton cocktail by measurements in the same experiment:**
  - π^0 and η multiplicities are essential for the normalization of the dilepton spectrum and also to quantify the excess of thermal e^+e^-



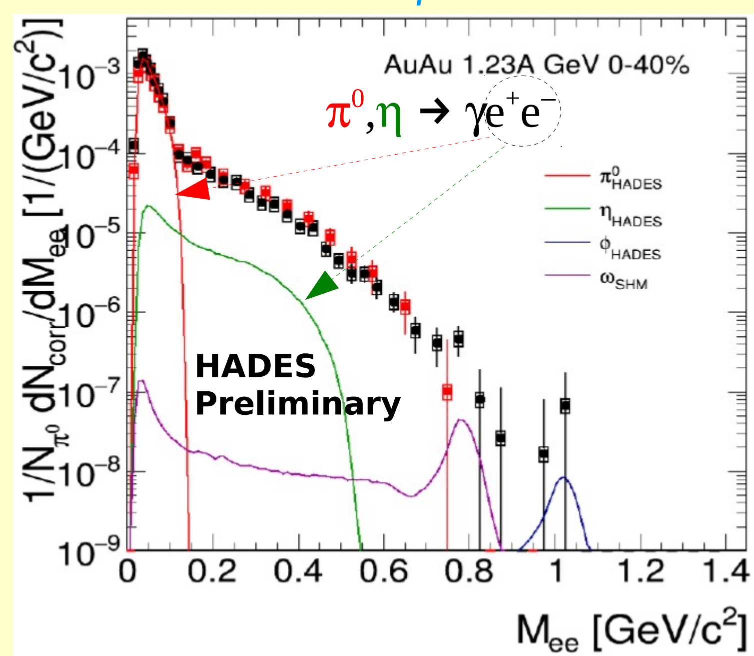


Measure: $\pi^0,\eta \rightarrow \gamma\gamma \rightarrow e^+e^-e^+e^-$

(γ–conversion in detectors with a probability ~ 1%)

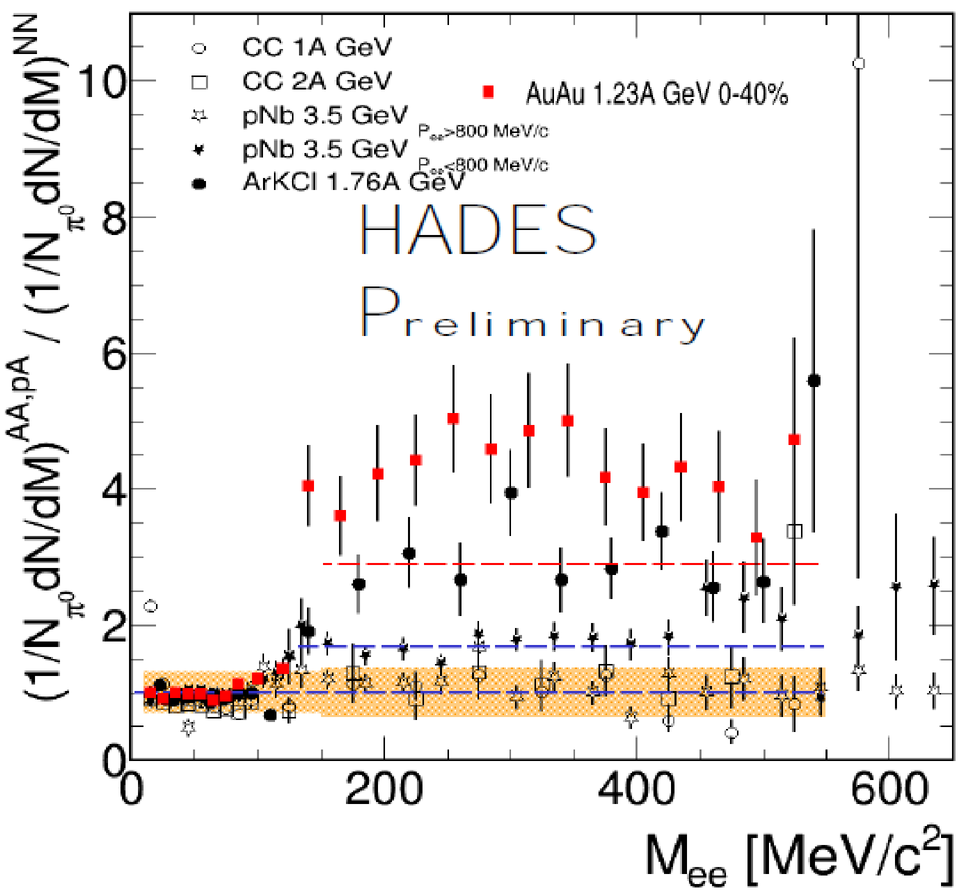


The enhancement comes from in-medium e^+e^-



Comparison of different collision systems

- **Thermal radiation from the fireball** *(normalized to the π^0 multiplicity and subtracted from the contribution of η):*



- The medium radiation emitted in ***CC*** (*HADES Collab., Phys.Lett. B 663 (2008) 43-48*) collisions is already present in ***NN*** collisions

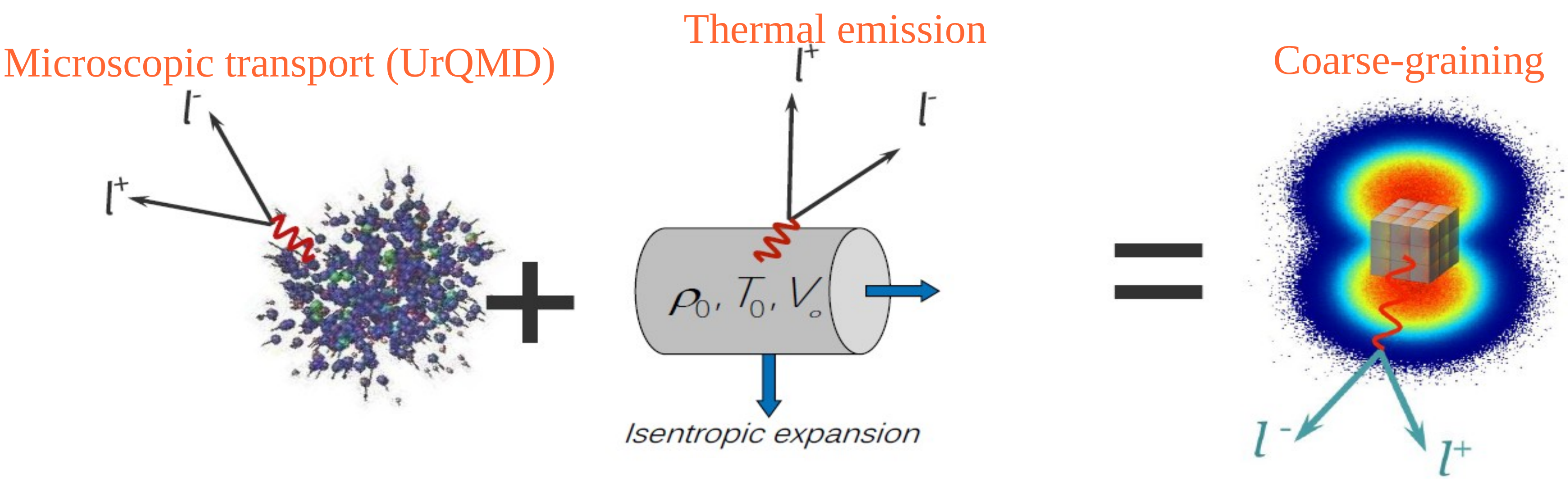
- Small excess of thermal radiation is observed in ***pNb*** (*HADES Collab., Phys.Lett. B715 (2012) 304*) for slow dileptons

- The dilepton enhancement is clearly visible for ***ArKCl*** (*HADES Collab., Phys.Rev. C84 (2011) 014902*) and ***AuAu*** collisions. Moreover, <u>the medium radiation scales stronger than linearly with the system size</u>

Points to the importance of the regeneration of baryonic resonances within the medium

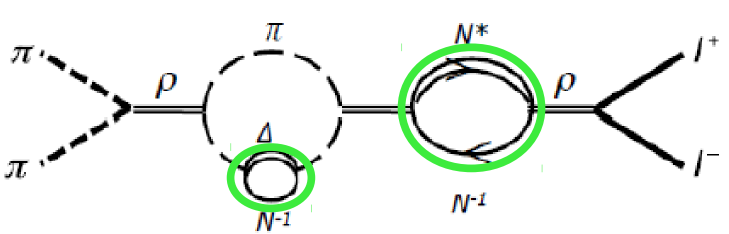
Description of the fireball evolution: Coarse-Graining hadron transport

(T. Galatyuk et al., Eur. Phys. J. A, 52 5 (2016) 131, F. Seck Master Thesis)



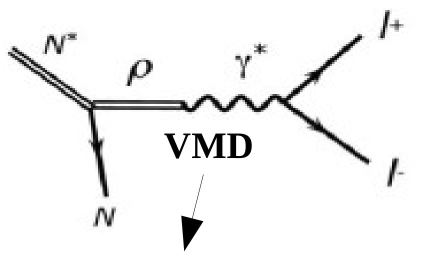
- **Theoretical description of the dilepton emission rates in HADES:**
  - Au+Au collisions are simulated with UrQMD *(Ultra Relativistic Quantum Molecular Dynamics)*
  - The volume of the fireball is discretized in *21 x 21 x 21* space cells of *1 fm³* and, thereafter, their evolution is analyzed in 30 time steps of *Δt = 1 fm/c* (*~ 280 k cells)*
  - For each cell the bulk properties are extracted: T, μ_B and collective velocity. The dilepton rates are calculated from these inputs and then they are summed up for all cells

$$\frac{d^3N}{dMdydp_t} \equiv \int_{t=0}^{\infty} \frac{d^4\varepsilon}{d\mathbf{p}} \left[T(\mathbf{x}), \mu_B(\mathbf{x}), \vec{v}_{coll}(\mathbf{x}), ..\right] d\mathbf{x}$$

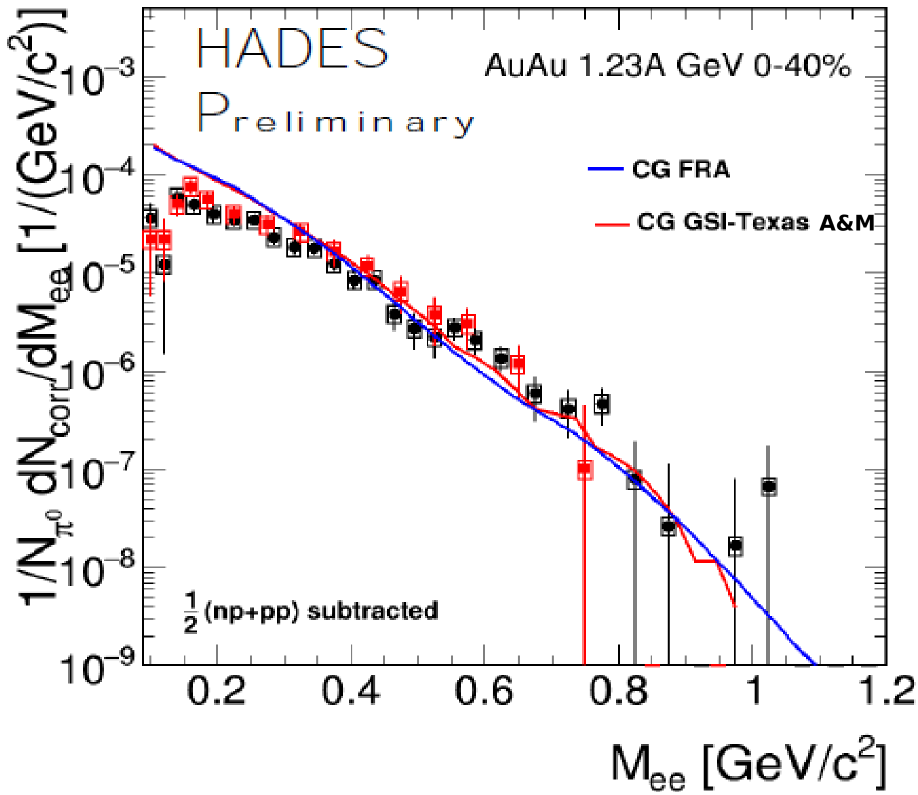


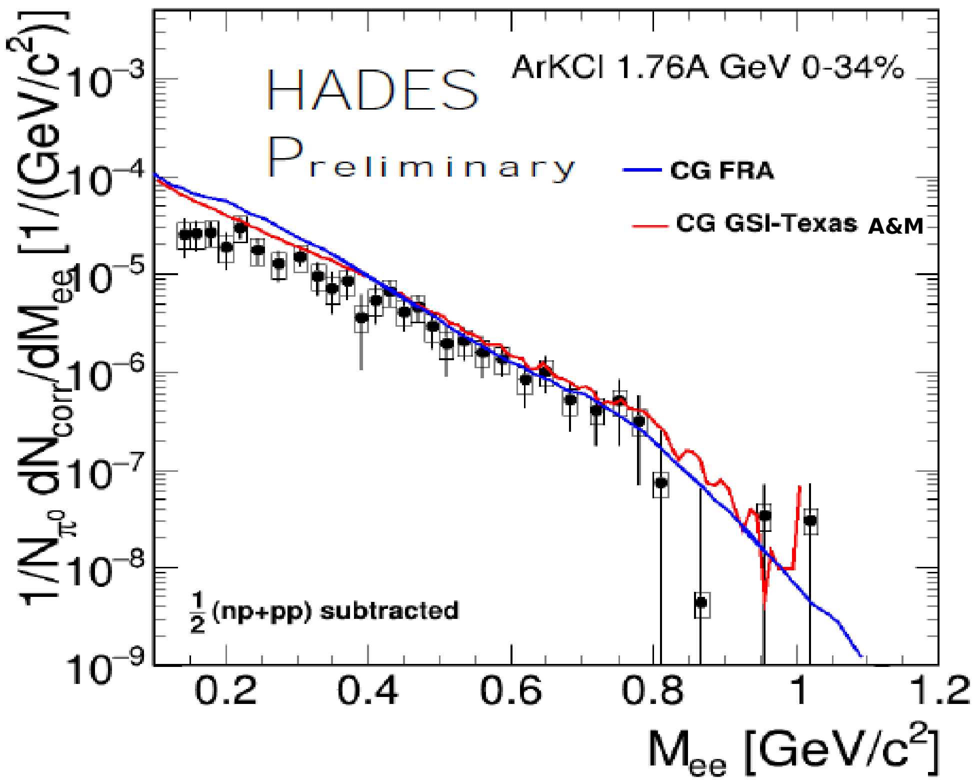
Comparison between Coarse-Graining simulation and data

- The dominant process for the dilepton production in HADES is the electromagnetic decay of **N***. Assuming the **VMD** model and a parametrisation of the in-medium broadening of the ρ meson (*Adv. Nucl. Phys. 25 (2000)*), the Coarse-Graining simulation gives:



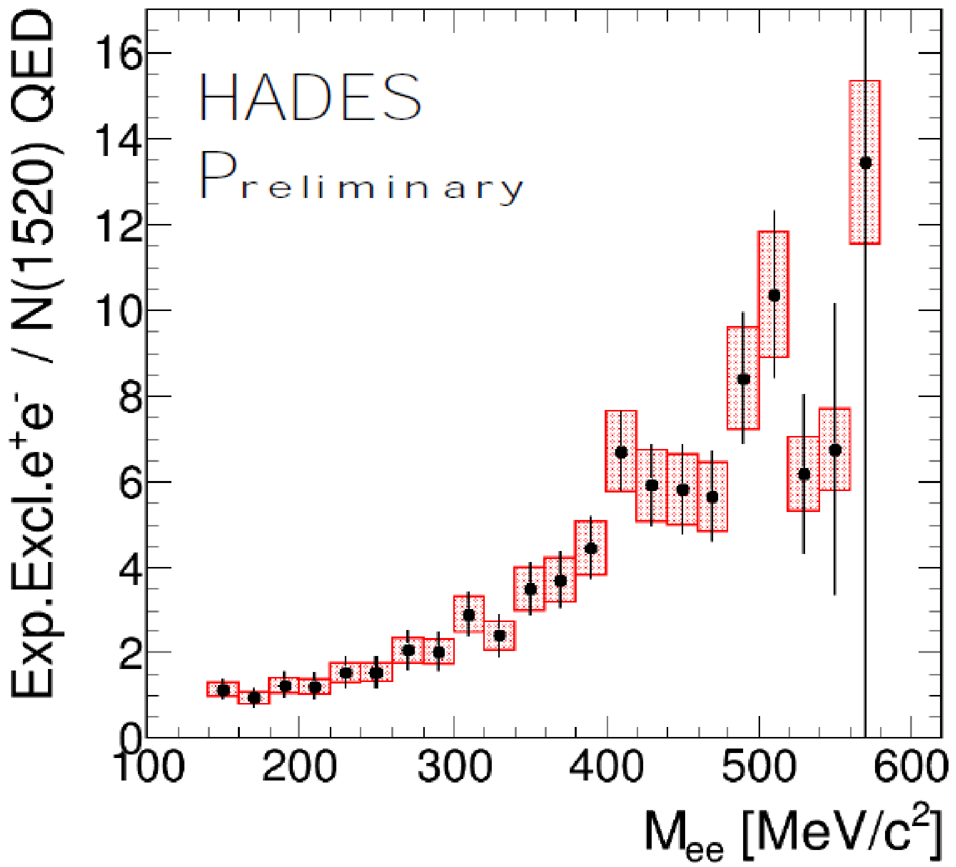
CG FRA: *Phys. Rev. C 92, 014911 (2015)*
CG GSI-Texas A&M: *Eur. Phys. J. A, 52 5 (2016) 131*

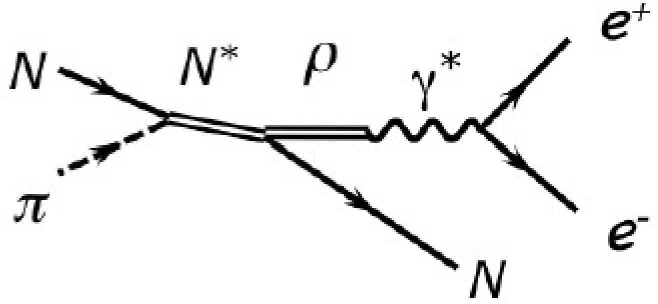




REASONABLE AGREEMENT WITH EXPERIMENTAL DATA!

Testing the VMD assumption: **data from $\pi^{-}p$ collisions using a π^{-}_{beam} of 0.69 GeV/c**



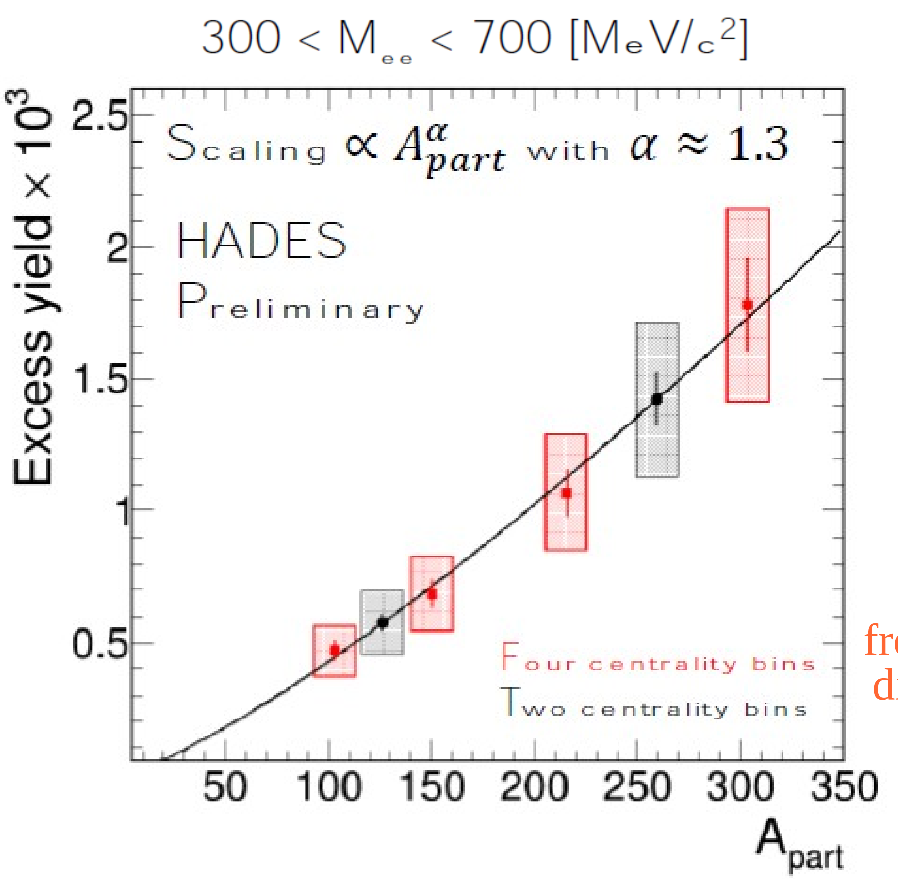


THE STRONG DEVIATION FROM UNITY CONFIRMS THE VALIDITY OF THE VMD MODEL

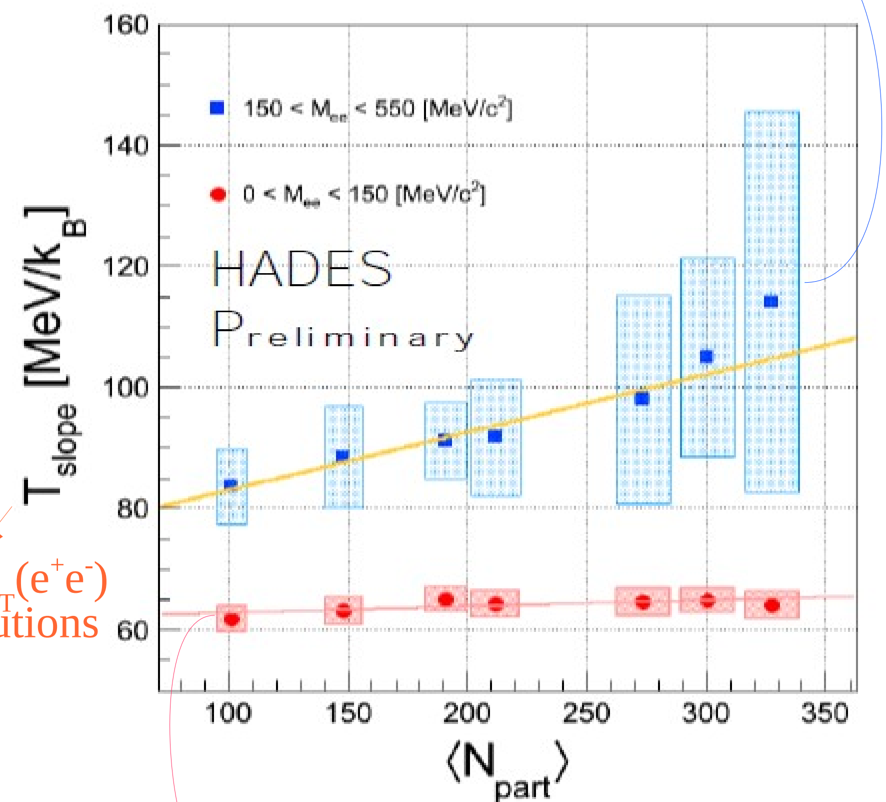
Lifetime and temperature of the fireball

- The centrality dependence of the dilepton excess indicates that <u>the most central collisions give rise to longer-lived and hotter fireballs</u>

Medium radiation dominated



from $m_T(e^+e^-)$ distributions



Freeze-out dominated

Summary and Outlook

- HADES explores baryon rich matter at SIS18. The experiment has collected high quality data on dilepton emission from both Heavy-Ion and elementary collisions

- **The excitation function of e^+e^- from Au+Au data at 1.23 AGeV is now completed:**
  - The data is well explained by the strong broadening of the ρ meson within the dense and "long-lived" fireball of HADES

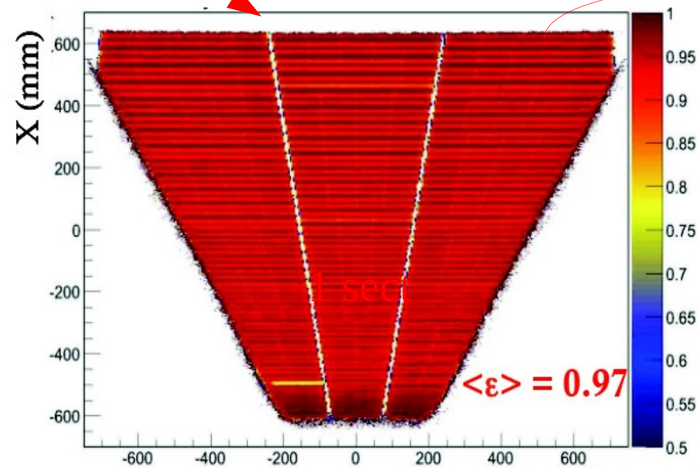
- **Outlook:**
  - **Now:** Upgrade of the HADES spectrometer for FAIR
  - **FAIR phase 0** *(2018-2019)***:** Ag+Ag at 1.65 AGeV and proton/pion induced reactions
  - **FAIR phase 1** *(SIS 100)***:** Ag+Ag reactions at 3.5 AGeV

SPARES

New detector for the Au+Au run: RPCs *(Resistive Plate Chambers)* → LIP

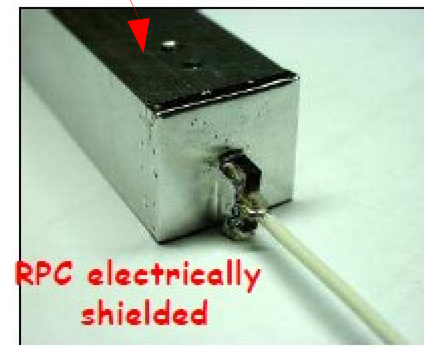
1 sector

Efficiency

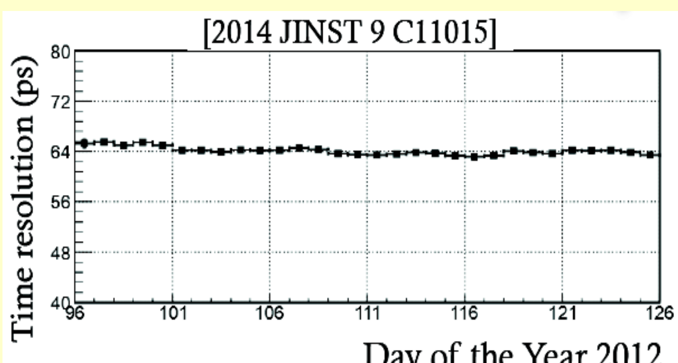


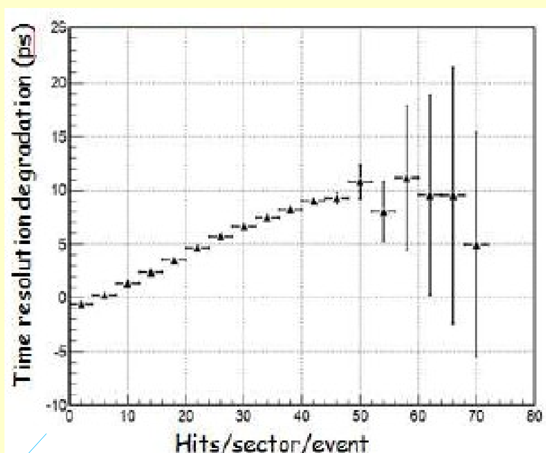
G. Kornakov et al. (HADES Collab.), JINST 9 (2014) no.11, C11015

1 RPC cell



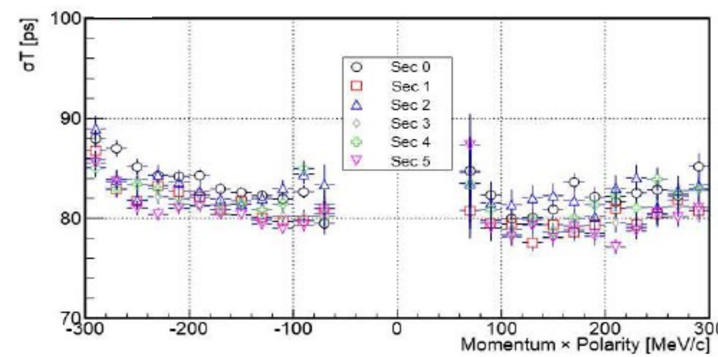
All particles: $\langle \sigma_T \rangle$ = 64 ps *(stable during the whole beam time)*





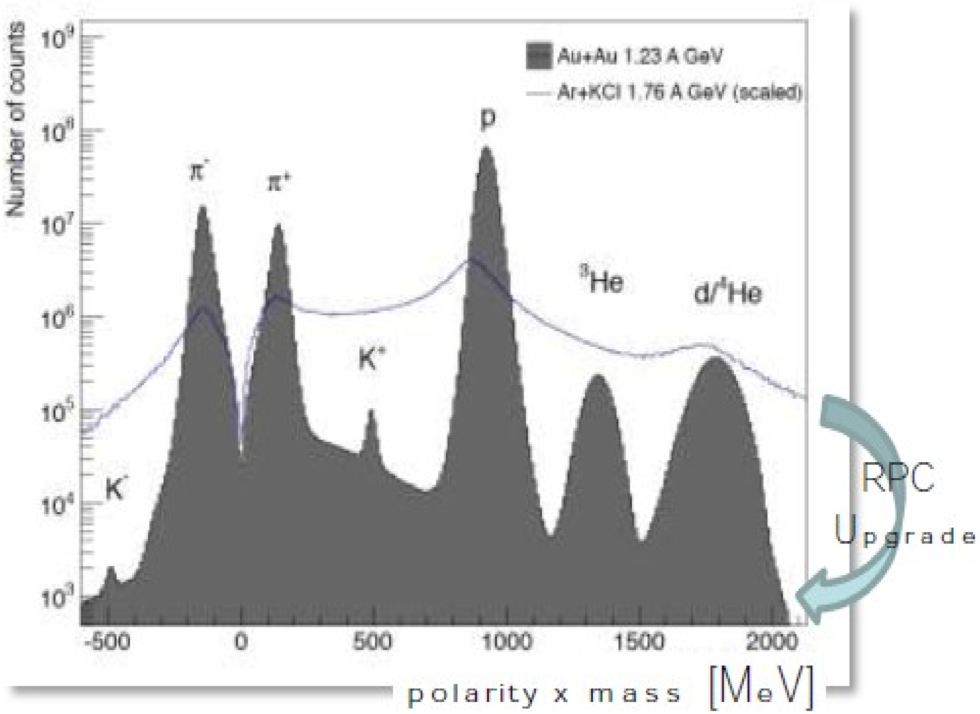
Excellent multi-hit time resolution!

Electrons and Positrons



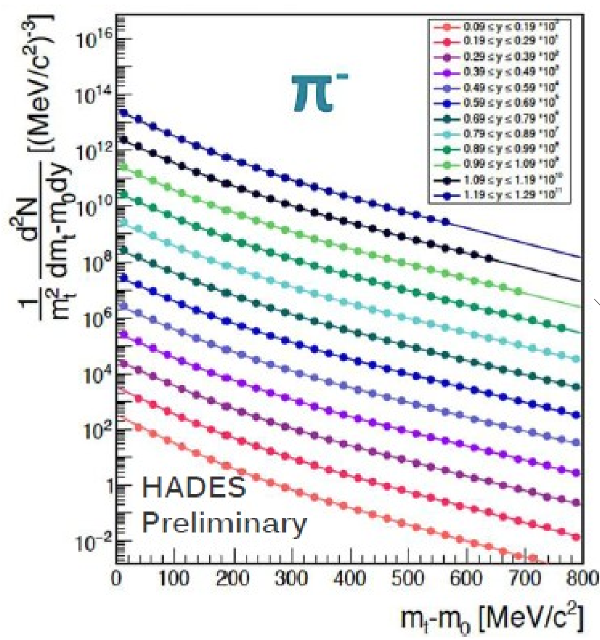
HADES performance after the RPC upgrade

- Invariant mass spectrum with cuts optimised for kaon detection:



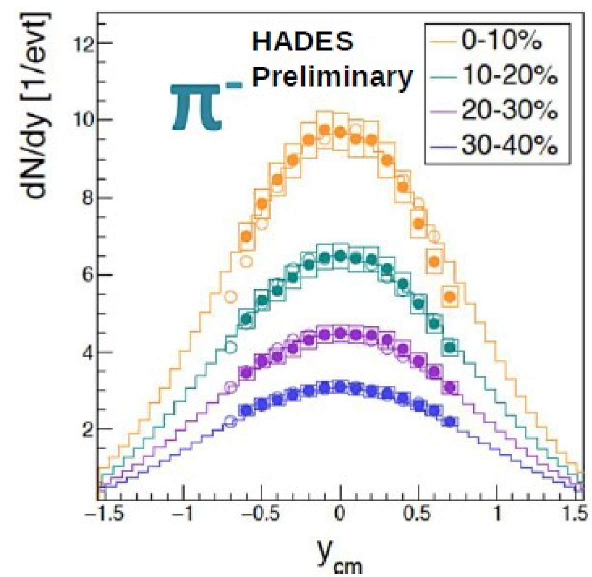
➔ **First measurement of K^- in the energy regime of 1-2 AGeV**

Charged pion reconstruction: π^0 multiplicity vs centrality

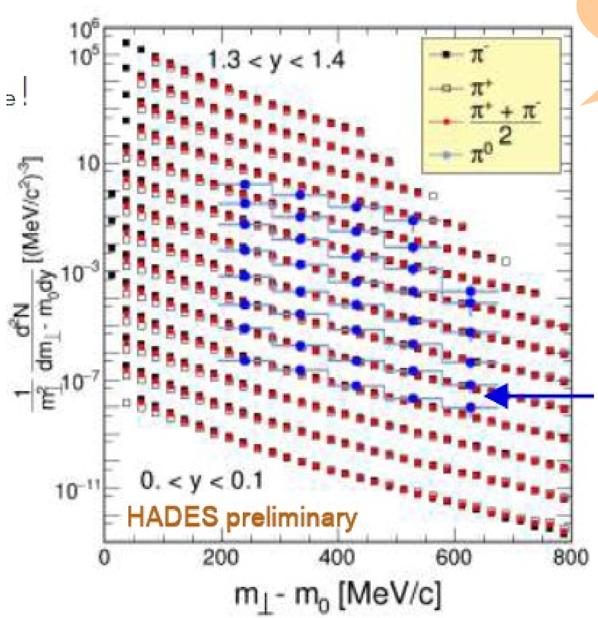


- The integration of the transverse mass spectra gives the pion yield per rapidity region *(the Boltzmann fit is used to extrapolate to the uncovered phase space):*

The slope gives T_{eff}



π^0 is consistent with $(\pi^+ + \pi^-)/2$



$\pi^0 \rightarrow \gamma\gamma$

Centrality	A_{part}	$M(\pi^+ + \pi^-)/2$
0-10%	303	13.4
10-20%	215	9.5
20-30%	150	6.8
30-40%	103	4.9
0-40%	191	9.4

Dilepton transverse mass vs centrality of the Au+Au collison

- The slope of each distribution gives the corresponding <u>effective temperature</u>